The ATLAS Upgrade Program and US Participation

Introduction and Overview

The LHC physics potential at the energy frontier is very rich. The current 7 & 8 TeV LHC run through the end of 2012 has been remarkably successful with 269 ATLAS papers submitted to date. The Higgs discovery garnered worldwide attention and ushers in a new era of Higgs physics, while the current searches point us to a need to probe more deeply the TeV the multi-TeV energy scale for evidence of physics beyond the Standard Model.

The High Luminosity LHC (HL-LHC) provides the means to carry out that program[1]. This compelling physics program is described in detail in the Snowmass energy frontier reports[2] and the ECFA Workshop[3]. The LHC has two scheduled long shutdowns (LS2 and LS3), with the start of HL-LHC collisions in ~mid-2025 (summarized below) and with concomitant upgrades of the ATLAS detector, which are described in the following sections. The Phase II upgrades focus on two distinct broad areas: the replacement of the current tracker with an all silicon device; and a coherent set of subsystem upgrades aimed at improving the trigger capabilities and making it robust enough to handle an environment with 140 or more mean number of interactions per crossing. The ATLAS Phase II Upgrade is designed to meet those challenges by preserving or improving the current physics capabilities of the detector.

Run Period	Cumulative Integrated Luminosity	Peak Instantaneous Luminosity
Run 1+2	150 fb^{-1}	10^{34} $cm^{-2}s^{-1}$
Run 3	350 fb^{-1}	2×10^{34} cm^{-2} s^{-1}
Run 4+	3,000 fb^{-1}	5×10^{34} cm^{-2} s^{-1}

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026-2035
LHC		LS1		Run 2			LS2		Run 3			LS3		Run 4…
ATLAS Analysis														
ATLAS Ops														
ATLAS Phase-I	preprod			construction		install/commiss								
ATLAS Phase-II					preprod			construction				install/commiss		

The Current ATLAS Detector and US Roles

US Physicist Activity (2013)	FTE
Ops/Computing	142
Analysis	280
Upgrade R&D	48
Phase I construction	14
TOTAL	484

The US ATLAS detector construction cost was $165M, or about 20% of the 'core' cost (i.e no manpower or contingency) of ATLAS. The US contributed intellectual leadership and developed unique expertise in: the Silicon Pixel (IC, mechanics) and Strip Tracker (leadership); the TRT (modules, electronics); the LAr Calorimeter (front end electronics, LVPS); the Tile Calorimeter (modules, electronics, LVPS); the Forward Muon system (chambers, electronics); and the Trigger and Data Acquisition system (core software, ROIB). Those construction roles evolved naturally into the current operations responsibilities. US ATLAS consists of 44 institutes, 600 physicists (484 FTE including 130 FTE postdocs and 180 FTE graduate students) and about 200 technical personnel (130 FTE), with the majority of technical personnel supported by either the Operations Program or the Phase I Construction Project. A snapshot for 2013 physicist activities is shown in the table. The Operations/Computing component of 142 FTE represents about 20% of the effort required to operate the ATLAS detector; the result is that the detector has operated with 93% data-taking efficiency. The size of the US analysis effort (280 FTE) has allowed US physicists to achieve the breadth and depth required to play significant roles in all analysis areas as well as provide overall physics leadership (3 of the last 9 physics coordinators have been from the US). This analysis effort is key to training the next generation of US particle physicists. Note that Phase I construction activities have yet to ramp up, but for the Phase II construction period (mid-2017 to mid-2023) we would expect Upgrade R&D and a large fraction of Phase I FTE to transition to Phase II construction.

The ATLAS Phase I Detector and US Roles

The Phase I detector upgrades are motivated primarily by the increasing luminosity and associated pile-up rate (an average of 55 interactions per bunch crossing are expected at a peak luminosity of 2×10^{34} cm^{-2} s^{-1} and 25 ns bunch crossing), which will lead to an increased trigger rate. The 100 kHz readout rate constraint for most of the front-end electronics and a physics need to maintain a low p_T lepton threshold (< 25 GeV) at the level-1 trigger (to preserve the physics acceptance that drops rapidly with higher thresholds) means the primary focus of the Phase I upgrade is on the development of additional handles to control the increasing trigger rates while preserving physics acceptance. The upgrades for Phase I consist of an increased granularity in the calorimeter trigger, a new Small Wheel forward muon detector and associated trigger and readout electronics, a Fast Track Trigger (FTK), and other Trigger/DAQ upgrades including the ability to create topological triggers at Level-1. The US scope of the Phase I upgrade construction project consists of:

- **Upgrade of the Liquid Argon (LAr) calorimeter trigger readout electronics (front and back end)** by using fine segmentation of the calorimeter at the trigger level to reduce QCD jet background in the electron, photon and τ triggers and improve the turn-on curves for jets and electrons;
- **New muon Small Wheel detector alignment system, upgraded trigger and read out electronics** providing a reconstructed vector at the location of the Small Wheel in combination with equivalent information from the Large Wheel to minimize the impact of cavern background by reducing fake muons at L1;
- **Upgrades to the Trigger and DAQ system** with new capability introduced at the Level-1 trigger to provide more powerful topological selections and fast tracking algorithms at the level-2 trigger.

The Phase I upgrade LOI[4] provides the full details and the US ATLAS CDR describes the US scope in detail. Thirteen US ATLAS institutes participate in the Phase I upgrade construction project which received CD-1 approval ($33M) in October 2013 and is under review for NSF funding ($13M).

The ATLAS Phase II Upgrade and US Roles

The HL-LHC will be the proton-proton discovery machine at the high energy frontier and is the top priority identified by the European Strategy Group[5]; it will also provide a large dataset for precision measurements. It will begin colliding protons around mid-2025 with a leveled instantaneous luminosity of $5 \times 10^{34}\ cm^{-2}\ s^{-1}$ and 25 ns bunch crossing, with the aim of delivering an additional 2,500 fb^{-1} to ATLAS over about a ten year period. The ATLAS Phase II upgrade is described in the LOI[6]. The physics drivers for the HL-LHC derive from the large luminosity that extends the energy scales to allow us to probe the fundamental nature of matter via:

- **Study of the EWSB mechanism** with boson-boson scattering and precision measurements of Higgs coupling to the 5% and 30% level, and the first studies of the Higgs self-couplings;
- **Probing for signatures of new physics** predicted by models such as SUSY and extra dimensions well into the multi-TeV region;
- **Measurement of rare decay channels and precision mass measurements** enabled by these very large data samples can address issues such as the vacuum stability.

These physics goals in turn drive the detector requirements for events that may have a 140 or more mean number of interactions per bunch crossing. The detector challenges include:

- **Good lepton momentum resolution up to high transverse momenta** for searches for high mass gauge bosons;
- **The ability to trigger on and reconstruct low p_T leptons (including taus) and identify heavy flavors** in order to reconstruct complex SUSY cascade decays;
- **The ability to reconstruct leptons and heavy flavors in highly boosted topologies** to search for resonances in pairs of top quarks, W, Z or Higgs bosons and top physics;

- **The need for radiation tolerance and sufficient granularity,** in view of large particle fluxes, to maintain highly efficient tracking with small fake rates;
- **The ability to preserve the physics acceptance in the forward region** where large particle fluxes could compromise the performance of the hadronic endcap calorimeter and the forward calorimeter;
- **Compatibility of all detector system readouts with a new trigger architecture** capable of handling the new trigger requirements;
- **The need for sufficient computing and associated software** to handle these large data samples (however this is not part of a Phase II construction project)**.**

In the following sections we describe and motivate the individual subsystems with a focus on the US aspirations based on US expertise, capabilities, distribution of effort and infrastructure. Currently we have participation by 30 US ATLAS institutes in Phase II upgrade construction. Final decisions on upgrade responsibilities await the final TDRs expected in 2016.

All Silicon Tracker (Strips and Pixels) Upgrade and the US Scope

The new all-silicon tracker replaces the current silicon + TRT system and is the single largest upgrade project in Phase II. It consists of a set of barrels at small rapidities and disks at larger ones. The inner radii use pixel technology whereas the outer radii use strip technology. There is a tenfold increase in the channel count compared to the current tracker to 638M pixels and 74M strips. Thermal, mechanical, electrical and cost considerations are paramount and depend critically on a vigorous R&D program. Silicon sensors with their front end readout are known as modules and are mounted on flex circuits which in turn are bonded to a structural core that provides the mechanical support and cooling – this thermal-mechanical-electrical assembly is called a stave (see the LOI for a figure). The stave concept was developed by the US to address many of these issues and was adopted as the baseline design for the ATLAS tracker upgrade. Some of the baseline design performance qualities that have a direct impact on physics have been simulated under extreme conditions of 200 events per crossing (this illustrates the available headroom since the expectation is 140) and lead to the following observations:

- **Efficient and robust pattern recognition** is possible with 14 measurement planes since it is necessary for a track to have at least 11 associated hits to reduce fake tracks, even in boosted jets;
- **Good spatial location of tracks into the LAr calorimeter** is provided by 1 mm resolution in z;
- **High muon efficiency and resolution which can be combined with the toroid system** to provide a 20% improvement in mass resolution for $H \rightarrow \mu\mu$;
- **Efficient *b*-jet tagging with good light quark rejection**; the new tracker has a factor of 100 rejection for a 65% efficiency.

The proposed US scope builds on US expertise acquired with the current tracker and an extensive R&D program over the past many years. The US activities focus on various aspects of: module assembly-and-test for both the strip tracker and pixel detector; strip detector stave production; the pixel barrel support structure; and the readout for both systems. The following table provides a summary of the US project scope, with a series of checkmarks that justify the US scope. Note that in all cases the US activity provides an excellent training ground for students and postdocs and is key to our educational mission. The legend for the checkmarks is as follows:

R (=R&D)	U (=Unique)	S (=Schedule)	I (=Infrastructure)
An R&D activity pursued by US	Unique US project without other collaborators	A major production activity shared among many ATLAS institutes so if the US did not participate it would cause the schedule to slip	An activity that uses significant US based infrastructure/ facilities

Activity	R	U	S	I	Comments
Stave Modules Assembly	√		√	√	US groups have long standing expertise in precision micro-electronic assembly. US groups would produce 20% of the assemblies.
Staves - Mechanical	√	√	√	√	US has world class expertise in high performance carbon based thermo-mechanical components. US industry has unique expertise in bus tapes.
Staves - Electrical	√			√	US has digital/analog design capabilities which led to key circuit components being developed.
Stave Assembly	√		√	√	US groups would load 50% of the staves.
Stave/Pixel Readout	√	√		√	US groups have led the design of the High Speed Input/Output DAQ architecture
Pixel module readout IC fab	√		√		Joint ATLAS-CMS development via RD53 where US personnel have leadership roles. Testing involves students
Pixel barrel support fab	√	√	√	√	US has unique experience and in-house capability for construction with student QC work.
Pixel Module assembly/test			√	√	Many worldwide sites. Testing by physicists and students.
Pixel system integration		√			Many pixel community experts reside in US. Opportunity for physicists to assume operations leadership.

The total US subproject M&S cost, without contingency, is $20.9M; the basis of estimate is the ATLAS Phase II LOI which carried out a careful evaluation of core costs.

Silicon Strip Timeline		Pixel Timeline	
2016	TDR	**2016**	TDR
2018-2022	Production	**2018-2022**	Production
2022	Integration/Comiss	**2022**	Integration/Comiss
2023	Install	**2023**	Install

Trigger/DAQ Upgrade and the US Scope

In order to meet the challenge of preserving the physics performance in the HL-LHC era, the trigger upgrade will include a three-level trigger controlled by a Central Trigger Processor system and an upgraded readout/data acquisition system. Level 0 (L0) trigger decisions are based on information from the calorimeters and the muon system, while the L1 trigger uses refined calorimeter, muon, and tracking data. These upgrades will provide for topological capability, allowing triggers based on correlations between different objects, in both L0 and L1. These data are collected, buffered, and transferred by the readout system, which will also undergo major changes in Phase II. With this system we will be able to:

- **Preserve high efficiency for Higgs, $t\bar{t}$ and SUSY** by maintaining the Level-1 trigger thresholds for isolated electrons and muons at 20 GeV with an accept rate of less than 20 kHz. Over half the ATLAS publications in 2013 used single/multi lepton triggers to collect the data;
- **Allow efficient triggers using jets and missing E_T** in combination with event properties**;**
- **Readout and store the data** at a factor of four higher bandwidth;
- **More easily maintain the system** by the use of commercial components common across sub-systems.

The US scope builds on the skills in the US to focus on projects for which the US can provide unique intellectual leadership and which involve some of the most exciting new technologies used in the upgrade.

Activity	R	U	S	I	Comments
L1 Track/FTK Upgrade	√	√			US has led the Fast Tracker (FTK) being installed now, so that is essential to the Phase II L1 Track trigger and FTK upgrade both of which use a similar architecture.
L0/L1 Calorimeter		√			Builds on US group responsibilities for the Phase I L1Calo system and the Phase 0 topological triggers system (CMX).
High speed Readout	√			√	US groups have significant experience with DAQ hardware design from Run 1.

The total US subproject M&S cost, without contingency, is $7.3M; the basis of estimate is the ATLAS Phase II LOI which carried out a careful evaluation of core costs.

Trigger Timeline		Readout Timeline	
2017	TDR	**2017**	TDR
2018-2022	Production	**2017-2022**	Production
2023	Install/Commiss	**2023**	Install/Commiss

LAr Upgrade and the US Scope

The LAr Upgrade for the HL-LHC consists of two distinct components. The first is the replacement of the front and back ends with new all-digital front and back end electronics that continuously digitize the calorimeter cell signals at 40 MSPS, creating a far more versatile trigger capability than the current system (100 kHz maximum L1 trigger rate). These signals are sent off-detector via high-speed optical links. Thus, full-precision, full-granularity is available to the new back-end electronics. The second component addresses potential problems in the forward calorimeter (FCal) which are still under study, including space charge effects, HV drops, and heating of the liquid Argon. The proposal is to replace the FCal with one with smaller gaps and protection resistors to mitigate the effects. The features of the LAr upgrade that have an impact on the physics include:

- **Retaining the ability to trigger on low p_T electrons and photons** using the new TDAQ architecture;
- **Maintaining the current calorimeter acceptance in the forward direction for tagging jets** with a new FCal;
- **Measuring missing E_T under very high occupancy conditions;**
- **Providing a more robust and reliable system** capable of handling the increased radiation doses.

The US scope of the project exploits the long experience gained by US groups who are building much of the current and Phase-I LAr front end electronics and the FCal. The US groups will use their long experience and many years of R&D supported by the US ATLAS Operations Program to lead the work in preamplifier/shaper ASICs, high speed radiation tolerant ADCs and very high speed optical links.

Activity	R	U	S	I	Comments
Preamp/ shaper ASIC	√			√	Strong design teams have allowed US groups to develop two viable designs well ahead of other countries.
ADC ASIC	√	√		√	The experience gained with the current front ends and in developing the Phase I upgrade ADCs puts US groups well ahead of any other competing designs.
Optical link ASICs	√	√		√	The US has unique experience by developing the highest speed radiation hard optical links, putting it in a strong position for the Phase II upgrade. Some of this work is developed jointly by US CMS-ATLAS groups.
FCal construct.	√	√		√	US groups had a lead role in design and management of the original FCAL and have taken the lead on the R&D necessary to determine the impact of the HL-LHC environment on the current FCal.

The total US subproject M&S cost, without contingency, is $11.9M; the basis of estimate is the ATLAS Phase II LOI which carried out a careful evaluation of core costs.

Front End Timeline		FCal Timeline	
2017	TDR	**2017**	TDR
2019	Production review	**2019**	Production review
2019-2021	Component prod.	**2019-2023**	Construction
2021-2023	Front end bd prod.	**2024**	Install/commission
2024	Install/commission		

TileCal Upgrade and the US Scope

The Tile Calorimeter (TileCal) is the ATLAS central hadronic calorimeter. The Phase II upgrade replaces the on-detector and off-detector electronics completely, and replaces the mechanical structures housing the on-detector electronics and PMTs. The on-detector system will consist of electronics cards and PMTs housed in mechanical "mini-drawers", with all data and controls communicated using high-speed optical links. The front end electronics consist of five boards or systems. The improvements from the upgrade include:

- **Retaining the ability to trigger on jets using the new TDAQ architecture**, since 35% of the jet energy is in the Tilecal;
- **Measuring missing E_T in very high occupancy events;**
- **Radiation tolerance for the electronics** in the HL-LHC environment.

The scope of the US part is based on the TileCal R&D, largely conducted by US groups who also played a significant role in building the current TileCal system and the new power supplies (LVPS). Thus the US scope is: the LVPS system; the Main Board (MB) that processes the PMT signals; the front end board (FEB); and the detector control systems (DCS).

Activity	R	U	S	I	Comments
Front end board	√	√		√	US groups built and maintain the FEB. They have long and unique experience with this system.
Main board	√	√		√	US groups built and maintain the FEB. They have long and unique experience with this system.
LVPS	√	√		√	US groups stepped in to redesign the original power supplies, and now have unique experience with them
Detector control systems					US groups have experts in the detector controls system

The total US subproject M&S cost, without contingency, is $3.4M; the basis of estimate is the ATLAS Phase II LOI which carried out a careful evaluation of core costs.

TileCal Timeline	
2017	TDR
2019	Replace gap scint; final demonstrator
2020-2022	Drawer production
2023	Install/commission

Muon System Upgrade and US Scope

The muon system is undergoing a significant upgrade for Phase I, but in order to retain compatibility with the new trigger architecture for Phase II, the readout electronics cards on the chambers will be replaced (where possible). New functionality can be added to further improve the p_T resolution by using Big Wheel track segment information in the level-1 trigger. The upgrade impact on potential physics is due to the ability to:

- **Maintain p_T L1 trigger thresholds at 20 GeV/c at 40 kHz**, since low p_T muons are key to physics analysis;
- **Reduce the rate of fake high p_T muons to less than 10%;**
- **Improve the p_T resolution by 25-30% in the endcap spectrometers**.

Muon Timeline	
2017	TDR
2018-2020	Design CSM/ASIC
2020-2021	Design Mezzanine card
2021-2022	ASIC production
2022	Mezzanine card/CSM production
2023	Install/commission

Activity	R	U	S	I	Comments
Chamber Service Module		√			US groups proposed, designed produced, programmed and maintain all the current CSM modules. They are in a unique position to efficiently do the same for the new CSM modules.
Cables					The US proposes to provide the cables as part of the CSM project.
Mezzanine Card		√		√	US groups designed and produced the mezzanine cards used on the MDTs
ASIC	√	√		√	US groups designed the ASIC for use with the Phase I Small Wheel upgrade, and this ASIC will be an adaptation of that chip.

The scope of the US upgrades to the muon system (see table) focuses on the Endcap Muon system, where the US has long experience with the original construction and the Phase I upgrade (which provides a reduction of fake high p_T muons by providing a Small Wheel track segment). For Phase II, which now permits a longer latency, the Big Wheel information can be used to reconstruct a track segment to provide a similar fake rate reduction. That requires new front end electronics for the Big Wheel, both new front end ASICs that sit on mezzanine cards and chamber service modules (CSM) with new CSM cables.

The total US subproject M&S cost, without contingency, is $1.6M; the basis of estimate is the ATLAS Phase II LOI which carried out a careful evaluation of core costs.

Total US Phase II Upgrade Cost Estimate

The ATLAS Phase II Upgrade LOI details the 'core' (i.e. M&S) costs for the full upgrade (275M CHF). The US Phase II upgrade cost estimate is based on those costs and totals $45.1M (AY$) in M&S, i.e. not including technical manpower labor costs, common costs, or project management costs. The US aspirations described in the above sections generally match available US physicist manpower resources (the current physicist manpower deployed in non-operations and non-analysis activities matches an initial bottoms-up physicist manpower-needs estimate for the US scope described above) and form the basis of an initial US WBS we have produced which will be used to generate a resource loaded schedule and cost profile. However until the detailed resource loaded schedule is completed, we estimate the TPC for the US Phase II upgrade by using the original US ATLAS construction cost, the ATLAS Phase I LOI cost together with the current US ATLAS Phase I base costs (no contingency) to determine a 'scaling factor' that accounts for all on-project technical labor. Common costs and project management costs are added to that. A 50% top-down contingency is added to that total, until a risk based analysis can be carried out. **Thus the US Phase II Upgrade TPC is estimated to be $250M (AY$) over a 1.5 year pre-production period (2017 to mid-2018) followed by a 5 year construction period (mid-2018 to mid-2023)** – see the profile below.

AYM$	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	TOTAL
Operations	36	35	35	35	35	36	37	35	35	35	37	39	35	465
Phase I	2	8	11	15	9	1								46
Phase II					5	18	43	53	58	52	22			250
TOTAL	***38***	***43***	***46***	***50***	***49***	***55***	***80***	***88***	***93***	***87***	***59***	***39***	***35***	***761***

Conclusions

The physics goals are compelling and the ATLAS Phase II upgrade will achieve them. The US aspirations are based on unique US skills (or areas where a proportional US share is required to keep the project on its aggressive schedule) and are commensurate with past contributions. The projects serve to train US students and make good use of existing US infrastructure. The strong US R&D program continues to help reduce construction costs and those personnel will lead the construction as R&D activities are completed.

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[1] High Luminosity Large Hadron Collider: A description for the European Strategy Preparatory Group, L. Rossi, O. Bruning et al., CERN-ATS-2012-236 (2012).

[2] Snowmass Energy Frontier Summary Report (2013), http://www-public.slac.stanford.edu/snowmass2013/docs/preliminarypublic10-30/EnergyFrontier-10-30.pdf. The individual reports of the subgroups are: Higgs (http://arxiv.org/abs/arXiv:1310.8361); EW (http://arxiv.org/abs/arXiv:1310.6708); Top (http://arxiv.org/abs/1311.2028v1); QCD (http://arxiv.org/abs/arXiv:1310.5189).

[3] ECFA High Luminosity LHC Experiments Workshop: Physics and Technology Challenges, 94th Plenary ECFA Meeting (Nov, 2013) http://cds.cern.ch/record/1631032.

[4] Letter of Intent for the Phase-I Upgrade of the ATLAS Experiment Letter of Intent for the Phase-I Upgrade of the ATLAS Experiment, The ATLAS Collaboration, CERN-LHCC-2011-012 & LHCC-I-020 (2011).

[5] The European Strategy for Particle Physics Update 2013, http://council.web.cern.ch/council/en/EuropeanStrategy/esc-e-106.pdf.

[6] Letter of Intent for the Phase-II Upgrade of the ATLAS Experiment, The ATLAS Collaboration, CERN-LHCC-2012-022 & LHCC-I-023 (2012).

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Prof Steven M Ritz,
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9 December 2013

Dear Professor Ritz,

As the US considers the roadmap for its future in high-energy physics via the Snowmass and Particle Physics Project Prioritization Panel (P5) processes, it is timely to restate the importance of the strong continued engagement of the US in the ATLAS experiment at CERN.

The US has played central roles in the design, construction and operation of nearly all aspects of the ATLAS detector, making highly valued contributions to the liquid argon and tile calorimeters, silicon pixel and micro-strip trackers, transition radiation tracker, muon system, and the trigger and data acquisition systems. The US has also played major roles in technical coordination, including installation and commissioning of the detector. As ATLAS evolved from the construction to the data-taking phase, the US focus shifted accordingly, encompassing detector operations, data processing through the US Tier-1 and Tier-2 computing centres, and physics analysis. The US has led the efforts in several areas of software development and grid computing and has provided computing capacities that have been important for the success of the experiment.

The physics programme at ATLAS in the next decades is one of huge interest and excitement, and it requires significant detector upgrades. The US holds unique expertise within ATLAS in several areas of detector development that are pivotal to the upcoming upgrades, such as the design of ASICs and low-mass mechanical supports for the silicon detectors, and front-end readout electronics for the calorimeters. ATLAS as a whole relies on this expertise and the associated R&D efforts. US-ATLAS' important and timely contributions to the development of the Phase-1 and Phase-2 upgrades have helped catalyse cost-effective detector improvement programmes.

The US is the largest national team in the experiment and is represented at all levels of the ATLAS organisation. US physicists have held several principal roles and responsibilities within

ATLAS during every phase of the programme. It is notable that three of the last nine physics coordinators, and two of the four last deputy spokespersons, have been from the US.

The US is a highly valued partner and has been, and continues to be, a foundation of the ATLAS experiment. The ATLAS Collaboration appreciates the expertise and dedication of our US colleagues, their commitment to the experiment's success, and their willingness to contribute to that success in any manner that suitably aligns with their strengths and interests. Their historical knowledge of fundamental aspects of the detector and its workings, overall technical and scientific depth, and seasoned managerial presence have been integral to the success and achievements of the experiment. ATLAS has every interest in maintaining this productive and collaborative relationship. ATLAS management therefore takes this opportunity to express our strong support for a continued robust US involvement in ATLAS as we look forward to the next stages of physics exploration at the world's energy frontier.

Yours sincerely,

David Charlton

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